FINAL REPORT

Title: Forest management and socio-economic implications of prescribed burning by Yurok and Karuk Indians

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Acknowledgements

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Keywords

American Indians, California hazelnut, Fire Management and Policy, Indigenous resources, Prescribed fire

Abstract

Before widespread Federal and State fire exclusion and suppression policies were enacted, California Indians intentionally set prescribed burns to enhance the abundance and quality of species and habitats fundamental to their livelihood and culture. These fires are known as cultural fires, and they limited woody fuels and, in turn, mitigated wildfire spread across the landscape. In northwest California, the Karuk and Yurok Tribes are leading recent efforts to revitalize and expand the use of cultural fires, and thus, present a distinctive and timely opportunity to evaluate the socio-ecological effects of a formerly widespread land management practice that was and still remains integral to Indigenous culture and California ecology.

This project identified social processes that facilitate and constrain prescribed and cultural burns through interviews and surveys with fire managers across northern California, and evaluated the effects of cultural burns and fire proxy treatments in Karuk and Yurok territory on the production and harvesting of California hazelnut (*Corylus cornuta* var. *californica*) basketry stems by monitoring ecological plots and observing harvesting practices by basketweavers. The project also documented prescribed fire personnel, weather conditions, and fire effects on surface fuels.

Using an experimental approach, we found that compared to untreated hazelnut shrubs, pile burning, and propane torching treatments increased basketry stem production by 7- to 10-fold; while a cutting treatment increased production by 4-fold. These results demonstrate that these fire-proxy methods are an effective means to increase the production and the quality of basketry materials and, thus, could be integrated into forest restoration and fuel reduction projects when and where conditions for cultural burning is unfeasible.

Between 2015 and 2019 ~552 ha was burned in ~54 cultural fires in the study region. Our monitoring of hazelnut shrubs at these burn sites found that basketry stem production one growing season post-burn generated a 13-fold increase in basketry stems compared with shrubs at sites ≥3 growing seasons post-burn. Furthermore, areas burned at high frequencies (≥3 events from 1989 to 2019) had 1.86-fold greater hazelnut shrubs than areas burned <3 times. Observations of hazelnut basketry stem gathering found that 73% of gathering trips were to sites burned at high frequency. Basketweavers who did not have access to cultural burn sites travelled 3.8-fold greater distances to reach gathering sites burned by wildfires. Frequent, low-intensity cultural fire regimes support relatively dense hazelnut shrub stands, and increase basketry stem production, facilitating the maintenance and revitalization of Northwest California Indian basketweaving by reducing the costs associated with basketry stem gathering.

Interagency partnerships have supported prescribed and cultural fire expansion by providing supplemental funding and additional personnel. Increased communication among regulatory bodies, particularly land management and air quality management agencies, has also reduced bureaucratic constraints in permitting processes. Yet there remains a shortage of wildland fire teams and experts required to conduct environmental reviews to implement and plan these burns. The diversion of wildland fire teams from prescribed burns to support wildfire suppression, and statewide burn prohibitions have prevented cultural burns from occurring during ideal conditions. Permitting Indigenous communities, such as the Karuk and Yurok, to manage fire in their territories would support the expansion of prescribed burning and the revitalization of positive ecological and cultural processes.

Objectives

This project aimed to identify perceived prescribed burning regulatory constraints for Yurok, Karuk, USDA Forest Service, and other regional fire managers as well as to evaluate and model the costs and benefits of prescribed burning under current and projected conditions. An analysis of labor, equipment and supplies costs across agencies and burn areas on public, private, and Tribal lands sought to compare how these forms of ownership affect costs and prescribed burn site selection. An evaluation of prescribed fire benefits aimed to include the reduction of wildfire risk and cultural opportunities (i.e., basketry materials) from post-treatment ecological changes. The project used harvest efficiency rates and travel times to harvest locations to compare prescribed burn areas, unburned areas, and wildfire areas to identify if cultural fire management objectives are met. Additionally, the project intended to evaluate property ownership types at harvest locations to determine if property ownership affects Indigenous burning and resource access. The guiding questions for these objectives are:

1. Do prescribed burns affect the efficiency of harvesting fire-dependent resources in Yurok and Karuk territories? Do travel times to access resources differ within and among prescribed burn, non-burned, and wildfire areas within Yurok and Karuk territories?
2. Does land ownership affect the locations of prescribed burns as well as sites where Tribal members harvest fire-dependent resources?
3. What are the current and projected economic costs and benefits associated with conducting prescribed burns in Yurok and Karuk territory as well as on Forest Service lands? Do specific environmental/land use policies affect the distribution or extent of prescribed burns?

Although the project initially aimed to investigate the reduction of fire suppression costs by prescribed burning programs, and the creation of job opportunities and timber products from fire restoration treatments, these data were unavailable or unobtainable, preventing robust analysis.

Background

Across many different ecosystems, Indigenous burning has been shown to impart positive effects on human and ungulate foraging returns, habitat diversity, and species abundance, as well as the mitigation of wildfire spread by reducing fuel loads, fire intensities and resulting severities (Gottesfeld 1994; Kepe 2005; Sheuyange et al. 2005; Bilbao et al. 2010; Bliege Bird et al. 2012; Fowler 2012; Welch et al. 2013; Sletto and Rodriguez 2013; Codding et al. 2014; Coughlan 2014; Seijo et al. 2015; Trauernicht et al. 2016).

In California, fire is a critical biophysical process (Sugihara et al. 2018), and anthropogenic fires set by California Indians had profound effects on fire regimes preceding colonialism (Skinner et al. 2009; Crawford et al. 2015; Klimaszewski-Patterson and Mensing 2016; Taylor et al. 2016). These anthropogenic fires were integral to the culture and economy of California Indians through the way they enhanced subsistence and ceremonial resources (Lightfoot and Parrish 2009; Anderson 2018). 20th century fire exclusion policies to protect timber commodities and structures drastically reduced the relative spread of fire (Stephens et al. 2007; Stephens and Sugihara 2018), dispossessed Indians of their land, and prohibited Indigenous burning and culture (Huntsinger and McCaffrey 1995; Lightfoot and Parrish 2009; Aldern and Goode 2014; Lake et al. 2017; Norgaard 2019).

Presently, northwestern California Indian Tribes such as the Karuk, Yurok, and Hoopa are leading efforts to re-introduce prescribed burning by forming partnerships with public land and fire agencies as well as non-governmental organizations (Underwood et al. 2003; Levy 2005; Salberg 2005; Long and Lake 2018). Amongst these Tribes, prescribed fires are widely accepted and known colloquially as 'cultural fires' or 'cultural burning'.

One of the major objectives for conducting cultural burns in Karuk and Yurok ancestral territories (Fig. 1) has been to enhance the production of basketry materials for Indigenous basketweavers (Hunter 1988; Senos et al. 2006). One of the most highly valued and coveted species for basketweaving are the young stems of California hazelnut (*Corylus cornuta* var. *californica*; Ortiz, 1998, 1993; Smith, 2016), a multi-stemmed, deciduous shrub. Hazelnut stems continue to be particularly important in weaving baby baskets (cradles), which are composed of ~300 hazelnut stems and currently are sold for ~$800.

Cultural burns manipulate the post-fire response of California hazelnut, stimulating it to re-sprout from underground buds (Fryer 2007; Clarke et al. 2013), and produce straight shoots whose stems are suitable for use in basketweaving. Historically, burning would occur predominantly in the summer and fall months, and sometimes in the spring (Lake 2007). Hazelnut stem regrowth would be harvested in the following spring (April/May) after one full growing season (spring burn 10-12 months, fall burn 18 – 21 months post-burn; Lake, 2007; O'Neale, 1932; Thompson, 1991). However, fire exclusion has created a scarcity of basketry stems for basketweavers (Heffner 1984; Ortiz 1993; Smith 2016).

Institutional support for cultural burning in northwest California initiated in 2013 through the prescribed fire TRaining EXchanges (TREX), and in 2014 the Six Rivers National Forest began the Roots and Shoots project on the Lower Trinity/Orleans/Ukonom Ranger Districts. TREX is a program under the 'Promoting Ecosystem Resilience and Fire Adapted Communities Together' agreement between the USDA Forest Service and The Nature Conservancy, that invests in cooperative and collaborative burning across the United States (Butler and Goldstein 2010; Harling 2015; Spencer et al. 2015). In Karuk and Yurok territory, TREX provides

financial and logistical support to develop burn plans, process permits, and mobilize fire personnel and equipment for burning, as well as support inter-governmental, inter-agency, and civil society partnerships. The Roots and Shoots project is a Six Rivers National Forest effort developed by the USDA Forest service and basketweavers to burn 176 acres within 25 forest areas containing ecocultural resources identified by Tribal members (Colegrove 2014).

While these partnerships are facilitating prescribed burning, many constraints persist (Schultz et al. 2018; Miller et al. 2020). A 2009 study of prescribed fire impediments found that prescribed fire managers in northern California were constrained by a narrow burn window, environmental and air quality regulations, and a paucity of trained personnel to conduct burns (Quinn-Davidson & Varner 2012). Indigenous communities often face additional constraints to expanding prescribed burning given minimal resources and infrastructure (Lake et al. 2017). Yet, Indigenous communities are well positioned to lead efforts to re-integrate fire onto the landscape because of their long-standing reliance on fire-enhanced resources, and recognition of fire benefits (Carroll et al. 2004; Roos et al. 2016; Lake et al. 2017).

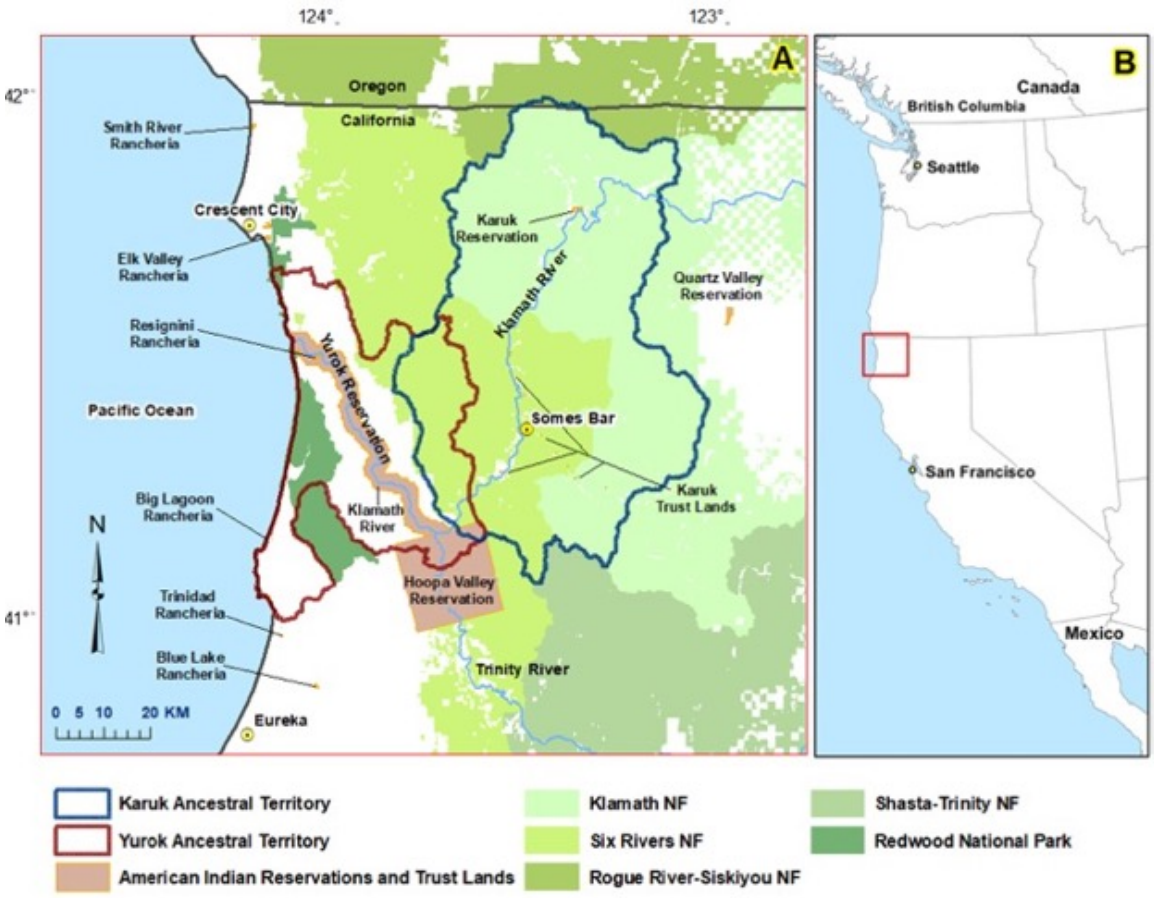

Figure 1. (A) Study Region with Federal Jurisdictional Boundaries and Karuk and Yurok Territories. Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff, 1963). **(B) Western Region of the United States of America.** The study region is depicted by the red box.

Materials and Methods

Effects of prescribed burning on cultural resources and fuel loads

We characterized the weather and fuel conditions of 30 prescribed and cultural burns in the study area by observing climate variables during burns, and collating data recorded by fire managers. To measure the effects of prescribed burning and other treatments on the production of hazelnut basketry stems for Karuk and Yurok basketweaving, we designed and analyzed experimental treatments on hazelnut shrubs based on local management techniques, and we monitored prescribed burn and adjacent sites with >10 hazelnut shrubs in 400 m^2 plots. To evaluate the effects of burns on potential wildfire risk, we conducted pre- and post-burn measurements of fuel loading using methods derived from Brown (1974) and Van Wagtendonk et al. (1998).

Experimental hazelnut treatments

In 2008, 27 stratified blocks (16 m^2) were established across a 10 ha Douglas-fir and mixed hardwood forest (500 m a.s.l.) in the Klamath mountains. Within each block three fire proxy treatments designed and used by Tribal members to promote basketry stem production were applied to California hazelnut shrubs, along with an untreated control. These fire proxy treatments were: A) cutting/coppicing of shrub stems; B) pile burning of small diameter (<2.54 cm) surface fuels between hazelnut stems; C) applying a propane torch to hazelnut shrub stems; and, D) a prescribed broadcast fire. Total stems and the potential 'usable' basketry stems were counted within each hazelnut shrub pre-treatment and 12 - 18 months post-treatment/burn. We developed Generalized Linear Mixed Models (GLMMs) to analyze these data using the glmmTMB and emmeans packages in R statistical software (R Core Team 2014; Magnusson et al. 2017; Lenth 2018).

Prescribed burn hazelnut monitoring

From January 2015 to March 2019, we established and monitored 48 plots (400 m^2) in relatively high-density hazelnut groves (≥10 shrubs) planned to be burned for hazelnut basketry stem production. Within each plot, we recorded hazelnut shrub density, overstory tree basal area (>10 cm dbh), burn frequency (1989 – 2019), and growing seasons since the shrubs were burned. Given that basketweavers prefer to gather in areas burned after only a single growing season, we also gathered data on the proportion of stems browsed by ungulates (e.g., deer and elk), and the burn season, within each of the plots surveyed one growing season post-burn. To evaluate the effects of growing seasons post-burn and environmental variables on hazelnut basketry stem production and hazelnut shrub densities, we employed GLMMs and Generalized Linear Models (GLMs) using the glmmTMB, car, and sjPlot packages in R statistical software (R Core Team 2014; Magnusson et al. 2017; Fox and Weisberg 2018; Lüdecke 2019).

Effects of prescribed burning and land ownership on cultural resource harvesting

From 2015-2019, we developed working collaborative relationships with basketweavers and hazelnut stem gatherers by attending 13 cultural fire planning meetings, 15 basketweaving classes, and by discussing our research interests at Karuk and Yurok Tribe governmental meetings. Through these collaborative exchanges, we attended hazelnut stem gathering trips, and requested and collected six gathering diaries from three basket weavers to evaluate where and

why basketweavers select hazelnut stem gathering areas. Moreover, we conducted 13 in-depth semi-structured interviews (30 – 60 minutes per interview) with Karuk and Yurok resource users and seven fire managers about fire-enhanced resource use and cultural burning that included questions on hazelnut burning, hazelnut stem and nut gathering, basketweaving, and the type of property ownership at burn sites.

During hazelnut stem gathering season (April/May 2015 – April/May 2019), we attended 17 hazelnut stem gathering trips, wherein we observed individuals gathering hazelnut stems and asked semi-structured and open-ended questions regarding basketry stem quality, and basketweaver gathering site preferences. During these trips, the sum of an individual's harvested stems and their time spent in a hazelnut grove were recorded to produce 55 independent gathering rates. We also recorded the distance travelled to hazelnut stem gathering areas from these trips and from basketweaver reports that we analyzed using a Wilcoxon rank sum test. Alongside these distances, the gathering site's fire history was also recorded and then classified either as a cultural fire site, wildfire site, or a fire excluded site. We also recorded the site's land ownership, ancestral territory, and site quality based on basketweaver post-harvest evaluations. From these data, we generated logistic models of hazelnut stem foraging rates across sites, and evaluated associations between gathering site fire type (wild, cultural) and territory (Karuk, Yurok, Hupa) by employing Pearson's Chi-square (χ^2) test of independence.

Facilitation and Constraints to Prescribed Fire Expansion

From 2014 – 2019, we observed prescribed fire planning and implementation in Karuk and Yurok Indian territories within the Klamath River watershed of northern California. Our observations of prescribed fire planning occurred at 13 Cultural Fire Management Council meetings on the Yurok reservation. At these meetings, we transcribed interactions and developed relationships with leaders of the organization. Planning also occurred during prescribed fire training exchanges, where we observed the logistical decision process to implement burns. Participatory observations were conducted during prescribed burning at the Yurok (2015 – 2019; $n = 8$) and Klamath (2016 – 2019; $n = 4$) prescribed fire training exchanges. During these events, we also inquired and discussed decisions made with fire managers and participants who conducted burns. We also spoke with managers about specific prescribed burns conducted by the USDA Forest Service on the Klamath and Six Rivers National Forests.

We also conducted semi-structured interviews with 18 fire managers from prescribed fire training exchanges in the Klamath watershed, and with fire managers who responded to an online survey. These online surveys were developed using Qualtrics surveying software (Qualtrics International, Inc., Provo, Utah) and then distributed in February - March, 2019 to 190 fire managers employed by the USDA Forest Service, National Park Service, Bureau of Land Management, US Fish and Wildlife Service, US Natural Resource and Conservation Service, the California Department of Forestry and Fire Protection (CAL FIRE), California Fire Safe Councils, and Tribes in 26 Northern California counties. The survey and interviews included questions on what facilitated the expansion in area and frequency of prescribed burns as well as their perceived constraints. To analyze these data, we generated descriptive statistics, and used a grounded theory approach to inductively code survey and interview responses (Glaser and Strauss 2017).

Results and Discussion

Prescribed Burn Characteristics and Effects on Fuel Loads

From 2015 to 2019, 64 prescribed broadcast burns occurred within Karuk and Yurok territories. An area of at least 552 ha was burned through prescribed fire training exchanges (TREX) on private and Tribal lands, while 13 prescribed burns (712 ha combined) were conducted by the USDA Forest Service (Table 1). Burning techniques and thus flame lengths varied depending upon site conditions (Table 2). However, strip-ignition backing fires were typically used in understories with the majority of flame lengths <1 m. Prescribed burns significantly reduced litter, duff, 1-h and 10-h fuels ($p < 0.001$), but not 100-h or 1000-h fuels (Table 3). Hence, the expansion of these burns have the potential to reduce wildfire spread and risk.

Table 1. Cultural and Prescribed Broadcast Burn Area from 2015 – 2019 in Karuk and Yurok Territory by Burn Program Management. Burns were conducted by the USDA Forest Service (USFS) and through the Prescribed Fire Training Exchange (TREX) led by Karuk and Yurok Tribal members in collaboration with non-governmental agencies, the USFS, Cal Fire, and others.

Territory	USFS			TREX		
	n	Σ Ha	x̄ Ha	*n*	Σ Ha	x̄ Ha
Karuk	13	712.0	59.0	38	341.0	9.0
Yurok	2	17.0	8.5	26	211.0	8.8

Table 2. Cultural and Prescribed Burn Areas Monitored from 2015-2019 with Weather Conditions. Prescribed Fire Training Exchange (TREX) burns occurred on Tribal and private lands and were led by Tribes and Fire Councils ($n = 21$) and USDA Forest Service (USFS) burns occurred on National Forest lands ($n = 9$). Standard errors (±) are in parenthesis, different letters denote significant differences using a t-test ($p < 0.05$).

Burn Type	Area (ha)	10-h Fuel Moisture (%)	Relative Humidity Range (%)	Temperature (°C)	Max Wind Speed (km/hr)
TREX ($n = 21$)	6.98 (2.21)	20.1 (3.2)[a]	35 – 48	18 - 24	13
USFS (n = 9)	12.62 (8.02)	12.4 (1.7)[b]	35 – 54	18 - 22	10
Combined mean	8.45 (2.73)	17.8 (2.3)	35 – 50	18 - 23	13

Table 3. Fuel Loads in Cultural and Prescribed Burn Areas Pre- and Post-Burn.
One hour fuels (<6 mm), 10-h fuels (6 – 25 mm), 100-h fuels (> 25 – 76 mm), solid (s) and rotten (r) 1000-h fuels (>76 mm), and litter and duff depths were systematically collected along three 10 m planar transects located randomly within 27 plots (400 m^2). Woody fuel measurements were converted to Mg ha^{-1} using formulas in Brown (1974). Using coefficients from Van Wagtendonk et al. (1998), litter and duff depths were converted to Mg ha^{-1}. Wilcoxon Rank Sum tests were performed to evaluate fuel loading differences pre- and post-burn.

Pre/Post Burn	Litter Mg ha^{-1}	Duff Mg ha^{-1}	1-h Mg ha^{-1}	10-h Mg ha^{-1}	100-h Mg ha^{-1}	1000-h (s) Mg ha^{-1}	1000-h (r) Mg ha^{-1}
Pre-	2.41 (0.24)	2.57 (0.33)	0.73 (0.14)	2.56 (0.33)	2.22 (0.35)	4.31 (1.28)	1.93 (1.63)
Post-	0.27 (0.40)	0.66 (0.19)	0.23 (0.04)	1.25 (0.15)	2.33 (0.51)	3.59 (0.90)	0.32 (0.14)
p	**<0.0001**	**<0.0001**	**< 0.0001**	**<0.001**	0.45	0.50	0.83

Effects of Prescribed Burning on Cultural Resource Abundance and Density

Experimental hazelnut treatments

All hazelnut shrubs that were treated with either pile burning, propane torching, and, or a prescribed broadcast burn increased the production of basketry stems from 7 to 10-fold in comparison with the shrubs in the untreated controls ($p < 0.001$, Table 4, Fig. 2). However, the quantity of basketry stems per shrub produced by the cut treatment (Estimated Marginal Mean [EMM] = 6.5, SE = 1.61) was only 4-fold greater than the untreated controls (EMM = 1.54, SE = 0.60, $p = 0.006$, Table 4). The three fire proxy practices examined here appear to be highly compatible for integration into larger-scale USDA Forest Service, or other fuel treatment programs (≥ 10 ha), and likely would require only minor adjustments to current understory mechanical fuel reduction practices to meet Tribal ecocultural objectives of increasing basketry stem production.

Table 4. Effects of the fire proxy and broadcast burn treatments (e.g., cut, pile burn, propane, broadcast) on hazelnut basketry stem production compared with the untreated control. Estimated Marginal Mean (EMM) is back-transformed from the log scale and averaged over the values of aspect and canopy classes. The contrast to control ratio is the treatment EMM to untreated control EMM (1.54, SE = 0.60). The confidence intervals, *t*-statistic and *p*-values were generated using the Dunnett method.

Treatment	n	EMM	Contrast to control ratio	Contrast SE	CI	*t* ratio	*p* value
Cut	15	6.45	4.19	1.87	1.38 – 12.7	3.22	0.0066
Pile Burn	15	10.98	7.13	3.05	2.46 – 20.7	4.59	0.0001
Propane	15	15.45	10.05	4.16	3.57 – 28.2	5.57	<0.0001
Broadcast	41	11.54	7.50	3.07	2.70 – 20.9	4.92	<0.0001

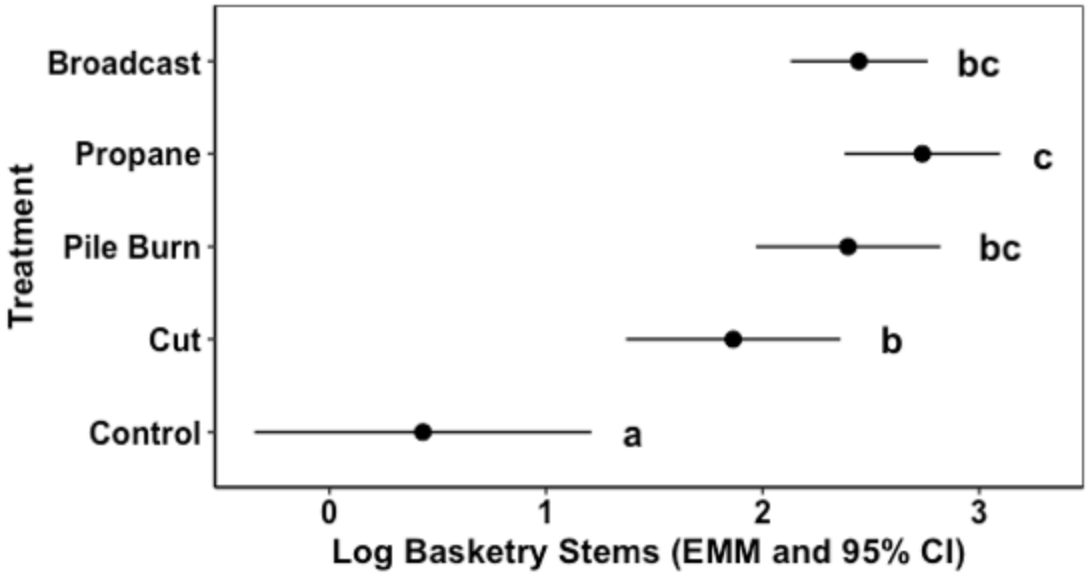

Figure 2. Fire Proxy Treatment, Broadcast Burn, and Untreated Control Effects on Hazelnut Basketry Stem Production. Estimated marginal means (EMM) of basketry stems with 95% confidence intervals (log scale) within the control and four fire proxy treatments. Letters indicate significant differences between treatments ($p < 0.05$).

Prescribed burn hazelnut monitoring

Hazelnut shrubs growing only a single season post-burn produced a 13-fold increase in basketry stems (Estimated Marginal Mean [EMM] = 10.776, SE = 0.87) than shrubs with three or more growing seasons post-burn (EMM = 0.801, SE = 0.08), and 6-fold greater stems than shrubs with two growing seasons post-burn (EMM = 1.807, SE = 0.25; $p < 0.0001$, Fig. 3). Hazelnut shrub density within plots was most strongly correlated to burn frequency (Fig. 4). Plots that were burned ≥3 times from 1989 to 2019 had 1.86-fold greater hazelnut shrubs (EMM = 71.0, SE = 9.53) than plots burned <3 times (EMM = 38.1, SE = 4.02, $p < 0.0001$, Fig. 4). Shrub densities in Yurok territory were 2.19-fold greater than shrub densities within Karuk territory (Wilcox test statistic = 74, $p < 0.001$, Fig. 4).

Frequent, low-intensity cultural fire regimes support relatively dense hazelnut shrub stands, and increase basketry stem production. This suggests that cultural burning for basketry stem production would be optimized at short intervals (e.g., every 3 – 5 years), and strongly concurs with California Indian basketweaver knowledge of hazelnut fire ecology, and practice of cultural burning (O'Neale 1932; Thompson 1991; Ortiz 1998; Anderson 1999).

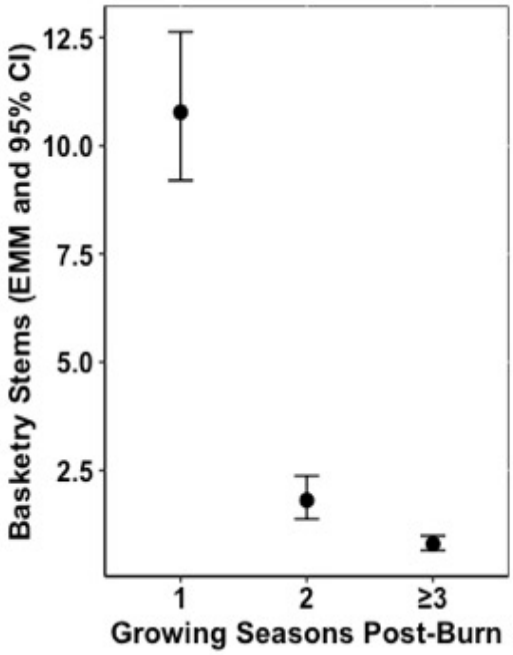

Figure 4. Hazelnut Basketry Stem Production and 95% CI with Growing Seasons Post-Burn.

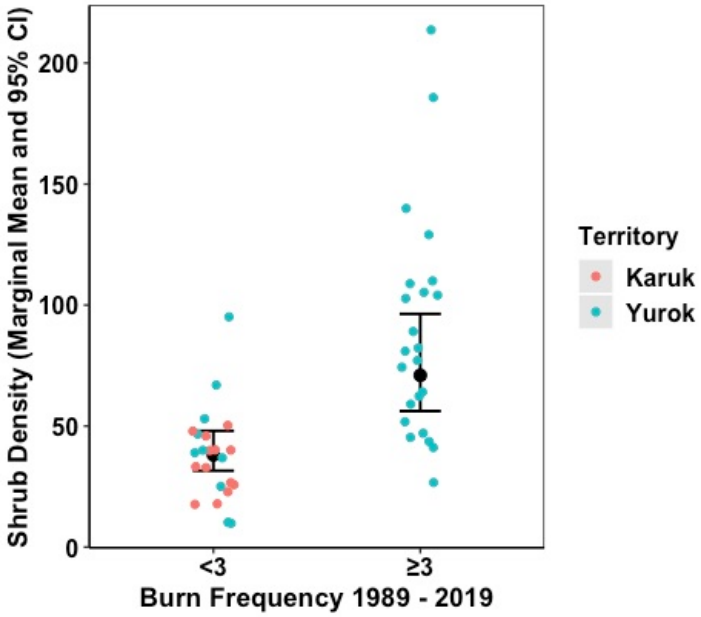

Figure 3. Hazelnut Shrub Densities with Burn Frequencies (<3 and ≥3 Burn Events) from 1989-2019. Marginal Means with 95% CI and plotted data points colored according to location within Karuk or Yurok ancestral territory (Figure 1).

Effects of Prescribed Burning and Land Ownership on Cultural Resource Harvesting

From 2015 to 2019, 90 distinct individuals were observed gathering hazelnut stems at 21 independent burn areas; 76% of these sites were culturally burned and 24% were burned by wildfires. Of these sites, 29% were on USFS land, 48% were privately owned, and 23% were Tribally owned fee or trust lands (Yurok and Hoopa Valley reservations). The majority of 89 gathering trips (73%) were to sites that were culturally burned ≥3 times between 1989 - 2019. Trips in Yurok territory all occurred at culturally burned sites, whereas the 20 trips to gathering sites in Karuk and Hupa territories were, according to Pearson's χ^2 test, significantly more likely to occur at wildfire sites (50% of all trips, $\chi^2(2) = 41.03$, $p < 0.0001$).While wildfires in this region burn hazelnut shrubs, basketweavers remarked that searching for hazelnut shrubs in these typically remote wildfire areas requires considerable additional time.

Basketweavers expressed that they would prefer to gather close to home, but few suitable burned hazelnut groves were located in close proximity to their residences. Of 49 trips to hazelnut stem gathering patches, harvesters traveled a median distance of 34 km one-way (range: 0 – 472 km) and an average of 60 km (± 10.9 km). Basketweavers travelled 3.8-fold greater distances to reach 11 wildfire gathering sites ($\bar{x}$ = 129 km, SE = 40 km) compared with 22 cultural burn areas ($\bar{x}$ = 38 km, SE = 6 km, Wilcox test statistic = 72, $p < 0.01$). Gatherers spent a mean 56 ± 16 minutes per hazelnut stem gathering site. At 22 prescribed burn sites, mean gathering rates were 4.9 stems/minute/individual while gathering rates recorded at four wildfire locations were reduced to merely 1.6 stems/minute/individual, and at a fire excluded site, the gathering rate was 0.5 stems/minute/individual (Fig. 5).

Cultural burning directly supports the maintenance and revitalization of Northwest California Indian basketweaving by reducing the costs associated with basketry stem gathering. In 2019, the CFMC President, Margo Robbins, shared that, "Ten years ago it wasn't often that you'd see a baby in a basket. Now there are lots of babies in baskets because of TREX". However, in Karuk territory land dispossession has been comparatively greater than in Yurok territory, thus in recent decades Tribal members have not been able to maintain as many hazelnut groves with consistent cultural burning. As a result, Karuk stem gatherers tend to gather in areas burned by wildfires, where they have found higher quality basketry stems. However, compared with culturally burned sites in Yurok territory, the gathering costs are higher due to increased travel and lower shrub densities.

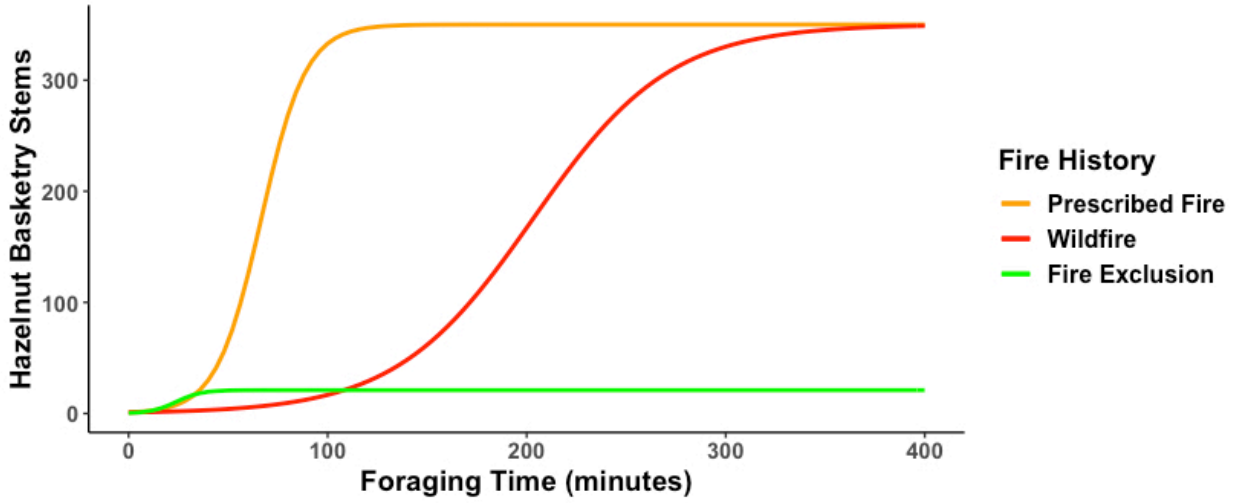

Figure 5. Fire history and hazelnut stem gathering rates modeled as logistic functions. Foraging time includes travel and gathering time. Gathering rates are based on average rates observed in 22 prescribed burn areas (5 stems/individual/minute), four wildfire areas (2 stems/individual/minute), and one fire excluded area (0.5 stems/individual/minute). Travel time to gathering areas was calculated from the average distance travelled one-way (34 km, prescribed burn; 129 km, wildfire; 2 km, fire exclusion) at a rate of 80 km/hour. The model assumes a gatherer aims to harvest 350 stems, based upon the average harvest observed from trips to nine prescribed burn areas. In areas where fire has been excluded for ≥3 years, basketry stem density is significantly reduced (Fig. 3), and thus, these sites impart highly reduced gathering rates. In areas burned by wildfires, stem gatherers travel 3.8-fold greater distances, and reportedly spend additional time locating hazelnut shrubs. Additionally, harvest rates may be reduced due to decreased shrub densities (Fig. 4). In contrast, stem gatherers travel shorter distances and have increased stem gathering rates in cultural burn areas that are frequently burned, where hazelnut shrub densities are 1.86-fold greater than wildfire sites.

Constraints and Facilitation of Prescribed Fire Expansion

Klamath Region Case-Study

Leadership by Karuk and Yurok Tribal members has been instrumental to expanding cultural and prescribed burning in California's Klamath watershed. Tribal fire managers express that they have overwhelming support for expanding cultural burning in the region, which is reflective of the vital role it plays in northern Californian Indigenous culture. Margo Robbins, the President of the Cultural Fire Management Council (CFMC) that leads cultural burning on the Yurok reservation, tells the story of how a 2012 grassroots survey of residents in the southeastern portion of the Yurok reservation identified expanding cultural burning as the highest priority for the community, which led to the creation of the CFMC. Fire managers in the region also identify that there is more demand for cultural burns on privately owned properties that they can provide, and that they do not sense opposition to cultural burning from residents. Given that many property owners in this region cannot obtain fire insurance, they feel that they must reduce risks on their own, and prescribed burning is an effective means to do so. The success of initial prescribed burns has garnered managers enhanced 'social license' and public support to expand the practice.

Expanding Prescribed Fire Capacity

The Karuk Tribe's Department of Natural Resources (Karuk DNR) has invested and raised considerable financial resources and has initiated numerous partnerships with non-governmental and governmental agencies to plan and implement cultural burns on land under federal jurisdiction, as well as private and Tribally-owned properties. The CFMC partners with the Yurok Tribal government, non-governmental organizations, and the California Department of Forestry and Fire Protection (CAL FIRE) to conduct cultural fires on the Yurok reservation. The Fire Learning Network and Prescribed Fire Training Exchanges (TREX), each coordinated by the Nature Conservancy, have provided critical initial funding and resources for the CFMC and Karuk DNR to initiate partnerships and conduct burns.

Karuk DNR, CFMC and the Yurok Tribe have leveraged TREX and Fire Learning Network resources to hire additional prescribed fire personnel. The increase in staffing has strengthened capacity and expanded prescribed and cultural burning in the region, however, managers believe it is still insufficient, and additional funds are necessary. The regional cost of preparing privately-owned fire-excluded sites for prescribed burning is between $1500 - $2500/acre ($600 - $1000/ha; N. Bailey, pers. com., 2018) and prescribed burning is ~$3800/acre ($1520/ha; E. Darragh, pers. com., 2019) based upon wages in FY 2018. Observed burns, on average, used 23 personnel, and spent 41 – 65 personnel hours per hectare burned (Table 5).

Tribal and community collaboration in fire management has the potential to expand capacity where federal and state agencies are overburdened (Lake et al. 2017). However, congressional appropriations for Tribal self-governance and fire management programs have never been adequately funded, despite treaty and trust obligations (Wilkins and Stark 2017). In the short-term, subsets of funds from federal and state agencies can support the legal and regulated burning programs of Tribes, but reliance on external funds that fluctuate with the politics of Washington DC and Sacramento is unsustainable. To create alternative funding streams, the Karuk Tribe recently established an eco-cultural revitalization fund to raise financial resources through private foundations and donors, and the Yurok Tribe has entered the carbon sequestration market to generate long-term funding for its forest and fire restoration program (Manning and Reed 2019).

Table 5. Average Personnel Hours and Fuel Used by Prescribed Burn Managers by Affiliation in the Klamath Watershed. Personnel hours were calculated by multiplying the time spent at a burn site by the total personnel conducting the burn. Personnel included all staff including burn bosses and wildland fire crews. USDA Forest Service (USFS) burns were conducted on the Klamath and Six Rivers National Forests in 2017. Prescribed Fire Training Exchange (TREX) burns were observed from 2017 – 2019. Standard errors (±) shown in parenthesis.

Affiliation	Burn area (ha)	Personnel (individuals)	Personnel (hr)	Personnel hr ha^{-1}	Fuel (l ha^{-1})
USFS (*n* = 7)	12.6 (8.0)	23.1 (4.6)	222.8 (71.1)	40.5 (4.5)	17.0 (2.3)
TREX (*n* = 19)	7.0 (2.2)	23.7 (1.3)	213.2 (39.8)	64.8 (13.1)	17.8 (2.6)

Regulatory and Budget Constraints

Obtaining air quality permits in this region has not been difficult because it is both relatively remote from high density population centers, and Tribes, NGOs and the Forest Service have good relationships with the North Coast Air Quality Management District. However, local, state and region-wide burn bans due to large wildfires or escaped prescribed fires in other areas have prevented prescribed burning from occurring in the Klamath basin during optimal prescribed fire conditions from 2016 – 2019. Officials within state and federal management agencies relay to local fire managers that allowing prescribed burns while wildfires burn elsewhere could create misperceptions that the government is not doing enough to protect homes.

The USDA Forest Service has flexibility to burn throughout the year, however, upper management often limits burning because of insufficient personnel or funds to conduct prescribed burns. The Forest Service typically requires that contingency fire engines and personnel are made available during burns to reduce risk. As a matter of practice, these engines are less likely to be available if there is a wildfire burning elsewhere, or if there was an arduous wildfire season preceding the fall prescribed burning season. Additionally, the fall prescribed burning season typically occurs at the onset of the fiscal year (October 1), and upper management are reportedly hesitant to allocate funds for prescribed burning if they anticipate a budget shortfall. Because of the long hours required to prepare and monitor a burn to ensure it does not escape, prescribed burning also typically requires that staff receive overtime pay. Overtime pay must be pre-approved for prescribed burns, which is another bureaucratic obstacle for prescribed burning in the region.

Prescribed Fire Expansion Across Northern California

Interagency Partnerships

Of 190 email and phone requests, 75 managers were surveyed and/or interviewed, producing a 40% response rate. These managers spanned nine national forests, the Pacific Southwest Forest Service regional office, Redwood National Park, Whiskeytown National Recreation Area, five CAL FIRE units, eight fire safe councils, four Tribes, the USDA Natural Resource Conservation Service and California State Parks (Fig. 6). Since 2013, 71% of managers stated that they have made progress toward increasing the annual area receiving prescribed burning treatments, yet concerted efforts by managers have produced only marginal improvements in achieving local prescribed burn targets and objectives.

The formation of interagency partnerships was viewed by managers as the most effective action to increase prescribed burning area (Fig. 7), as over 50% of managers reported that these interagency partnerships assisted them to surmount funding, personnel, and equipment limitations (Table 6). Partnerships between government agencies and NGOs particularly assisted managers in gaining support from local residents. Other important management actions included: 1) increasing agency capacity by hiring additional staff; 2) enhancing the qualifications of existing staff; and, 3) proactively planning and implementing burns (Fig. 7).

Interagency partnerships also helped surmount bureaucratic bottlenecks and navigate differences regarding smoke permitting. All federal fire managers surveyed stated that air quality permitting had either improved or had not changed since 2013, reflecting efforts to improve communication between public land agencies and the California Air Resources Board. However,

amongst NGOs and CAL FIRE managers, 41% stated that air quality permitting had declined in the same period. In regions near urban areas, local Air Quality Management Districts remain apprehensive toward additional emissions from prescribed fires, and impose cost prohibitive fees on prescribed fires. Thirty percent of managers identified that changing air quality regulations in the Clean Air Act to exempt smoke from prescribed burns as a priority and would effectively prevent regulatory discrepancies between different air quality management districts.

Across all managers, 41% believed public concerns toward prescribed burning had improved, whereas only 18% thought they had declined. Fire Safe Councils (FSCs) are a venue for communities to prepare for wildfire through prescribed burning, and have done considerable public outreach on the importance of prescribed burning and defensible space. Over 50% of all public land managers interviewed stated that community collaborations supported with public outreach, and only 26% of all managers felt that private properties discouraged the planning of prescribed burns 'most of the time'. Additionally, two public land fire managers shared that a greater investment in hiring public information officers would improve communication with residents in the wildland-urban interface to promote greater acceptance of prescribed burning.

Interagency and inter-governmental collaboration to initiate prescribed burning have established systems of polycentric governance to address the pernicious issue of wildfire risk in northern California (Crowder 2019; Kelly et al. 2019). These findings concur with those from recent studies on the constraints to prescribed fire in northern California and the American West (Quinn-Davidson and Varner 2012; Schultz et al. 2018; Miller et al. 2020). In particular, agencies require sufficient and sustained funding to hire personnel to meet their prescribed fire objectives, while effective collaborations among federal land management agencies and air quality regulators have been successful at advancing prescribed fire objectives throughout the American West (Schultz et al. 2018; Miller et al. 2020).

Wildfire Suppression

While wildfires have increased awareness of the importance of prescribed burning, they have also prevented managers from burning by reducing available personnel. Managers identified 'wildfires reducing available personnel' as the top constraint limiting their opportunity to burn, or 'burn window' (Fig. 8). In northern California, burn conditions are often ideal when southern California is experiencing wildfires, and personnel are requested to support in suppression efforts. However, as one manager noted: "Quite often we have to be on stand-by because there is a fire that doesn't even exist. This is preventing us from burning". Hence, in the fall burning season, northern California prescribed fire teams are unable to burn because agency leaders would like them to be available for relocation if a wildfire occurs. However, many managers also concede that the fire season has expanded with climatic changes, which also limits their access to wildland fire crews to conduct burns.

Across northern California, the prohibition of prescribed burning across the state by Forest Service regional staff and CAL FIRE upper management during wildfires or severe fire weather prevents implementation when the bans coincide with optimal prescribed fire conditions in other regions. Even without a statewide burn ban, wildland fire teams are prioritized for wildfire suppression, and often sent to other regions, or prevented from conducting prescribed burns so that they are available for a potential wildfire. Expanding prescribed burning requires major changes to wildfire management in order to reduce suppression costs (Dunn et al. 2017; Ingalsbee 2017). Decentralizing permissible burn day decisions to reflect local ecological and

climate realities and providing regions with greater autonomy over their personnel would facilitate prescribed burn objectives.

Personnel and Funding Requirements

The greatest staffing needs for fire managers are trained wildland fire crews who can conduct and prepare areas for prescribed burns. Managers consistently ranked these crews as the most beneficial means to expand prescribed burning capacity, and managers ranked hiring personnel to implement burns highest amongst all categories to increase financial resources (Fig. 9). Managers also expressed that understaffing of environmental planners and cultural resource or other specialists who help conduct NEPA and California Environmental Quality Act (CEQA) reviews and studies for proposed prescribed burning slows their ability to burn. One manager stated that: "Recruitment of specialists to rural areas is difficult. Retention is also difficult due to heavy workloads and lack of support".

When asked about supportive changes to law and policy to expand prescribed fire, the most frequently suggested change identified by 32% of managers was to reform NEPA and CEQA. One manager believed a recent change to NEPA enacted in the 2018 Consolidated Appropriations Act of the US Congress would be beneficial as it allows wildfire resiliency projects to be categorically excluded from environmental review. Other managers believed that California legislation in 2018 that exempted certain fuel reduction projects from additional CEQA review (e.g., those already reviewed under NEPA), held promise for streamlining prescribed burning.

Many managers sense that fire policies are changing primarily as a consequence of the devastating wildfires in northern California in 2017 and 2018, but they report that they are stymied from substantial progress without increased funding. Within the federal agencies, some believe that the changes in wildfire suppression funding from the 2018 consolidated appropriations act will provide additional funds for prescribed burning. Yet, 72% observed that their budgets have been either stagnant or in decline.

On federal public lands, hiring additional fire management personnel remains a major constraint because the funding for these positions has been insufficient, and is determined by complex political appropriations (Pyne 2004; Hudson 2011). In response to the destructive 2017 and 2018 wildfires coupled with advocacy by organizations like the Northern California Prescribed Fire Council, the State of California has been adopting new legislation to expand personnel for prescribed burning (Crowder 2019). As required by Senate Bill 901 (2018), the state increased appropriations for prescribed burning, and when compared with the 2017-2018 budget, the 2019-2020 State budget funded ten new prescribed fire crews with 157 new positions (California Legislative Analyst's Office 2019; Crowder 2019). Managers expect these changes will contribute to increased prescribed burning in certain regions of the state with a larger WUI. Yet, a similar increase in positions to conduct California Environmental Quality Act reviews for planned projects will be necessary to compliment this expansion in prescribed fire crews.

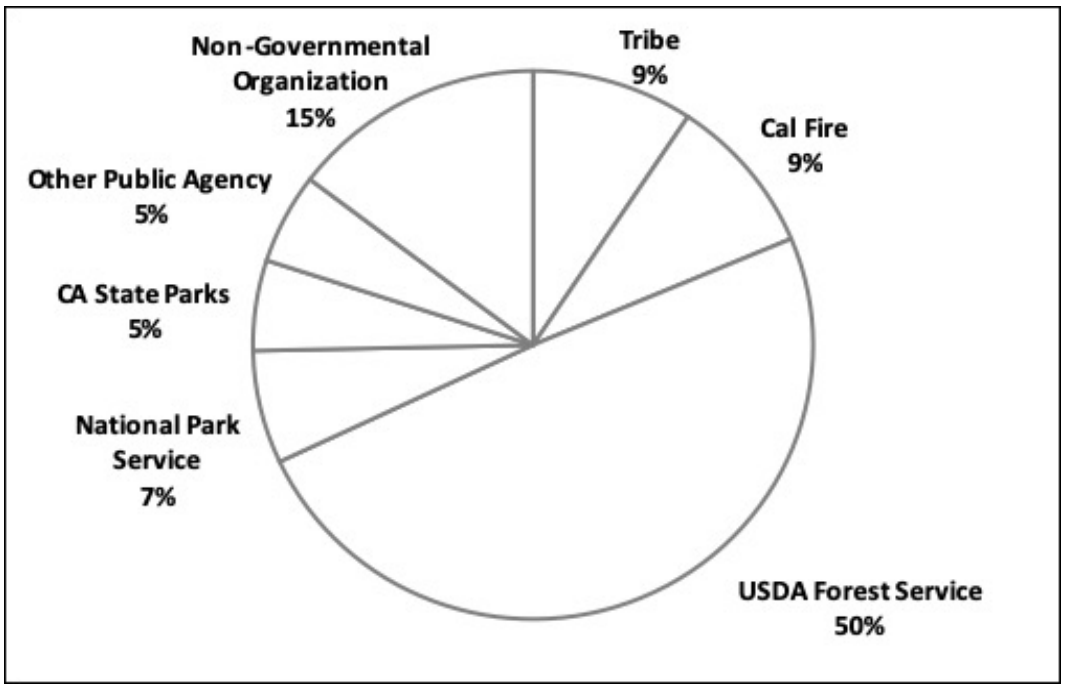

Figure 10. Affiliation of Fire Managers Who Participated in Surveys and Interviews. A total of 75 fire managers participated from 2016 – 2019.

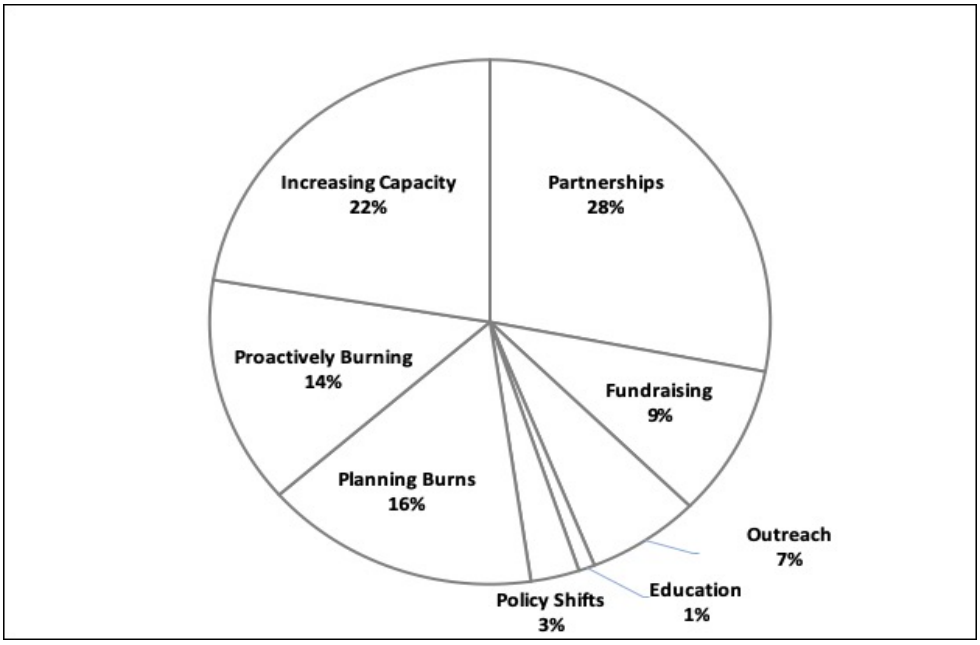

Figure 6. Effective Actions That Increased Prescribed Burning in Northern California. Fire managers were asked to identify their top three actions they took to increase prescribed burning in their agency, organization, or Tribe. Their responses were coded and then summed.

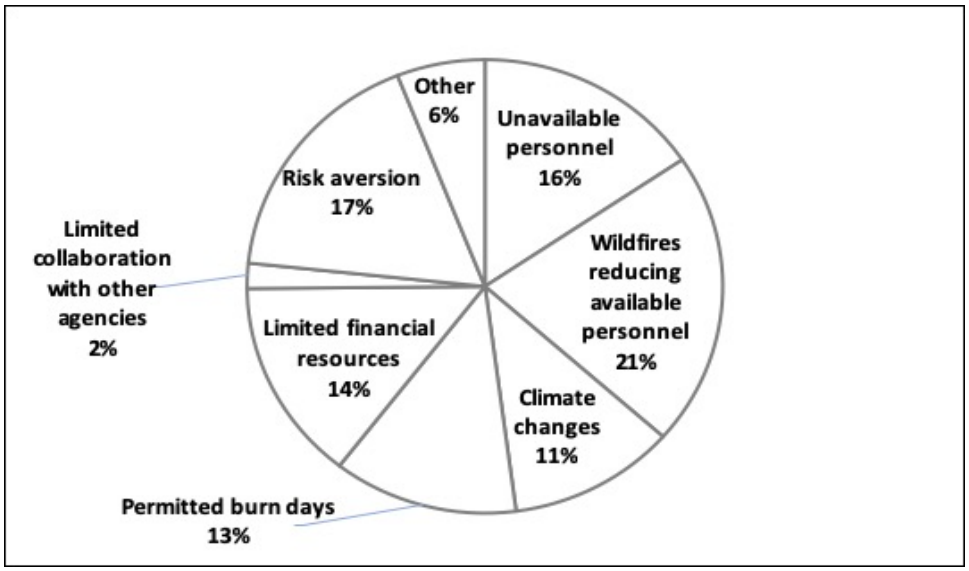

Figure 8. Top Three Burn Window Constraints. Fire managers were asked to rank the top three constraints to their agency's burn window, and their responses were summed. Other responses included National Environmental Policy Act procedures, ecological objectives and endangered species, limited available contractors and specialists, and air quality permits.

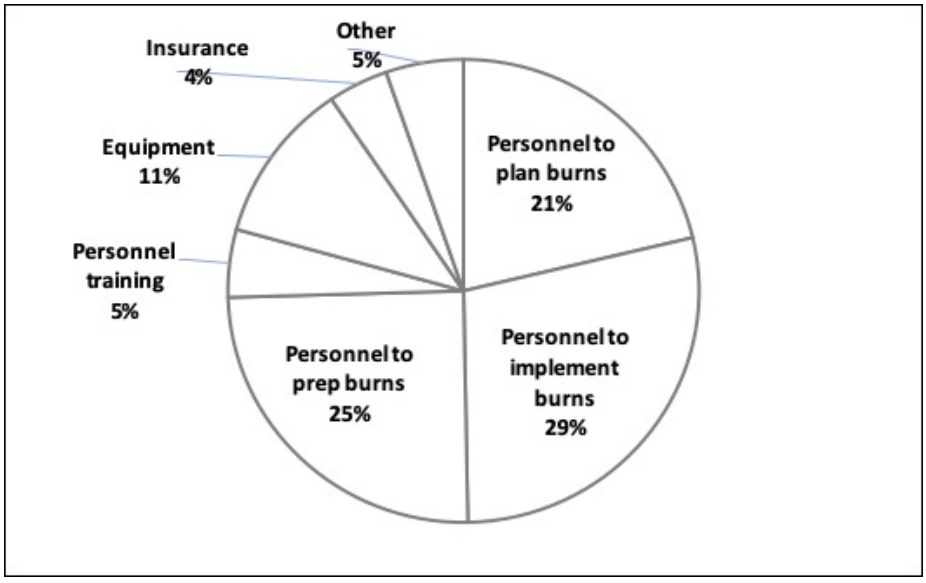

Figure 9. Top Three Budget Items to Increase Financial Resources Allocated to Prescribed Fire Expansion. Fire managers were asked to rank the top three budget items they would increase financial resources toward to expand prescribed burn area, and their responses were summed. Other items included National Environmental Policy Act specialists, public

Table 6. Agency/Organization Participation in Collaborative Prescribed Fire Programs. Managers were asked if their agency or organization participated in these collaborative programs. 'Other' programs in this category included the California Deer Association (5%), and a variety of other local programs, such as the Sierra Nevada Conservancy, the USDA Natural Resource Conservation Service Environmental Quality Incentives Program, and local fire departments.

Collaborative Prescribed Fire Program	Agency Participation (%)
Prescribed Fire Training Exchanges (TREX)	64
CAL FIRE programs	63
California Fire Safe Council	41
Joint Chiefs Landscape Restoration Partnership	20
Tribal Forest Protection Act	9
California Department of Fish and Wildlife	7
Other	32

Conclusions

The maintenance of hazelnut groves for basketry through repeated cultural burning is an excellent example of how California Indian resource management has been critical to ecological dynamics throughout California (Lightfoot and Parrish 2009; Anderson 2018). The expansion of cultural burns for a suite of fire-enhanced ecocultural resources would have cascading effects on species diversity and populations, and likely positive effects for a diversity of wildlife including endangered species like the California condor and Spotted Owl that feed in edge habitats and clearings (Cowles 1967; Biswell 1999; Franklin et al. 2000; Roberts et al. 2011; Nabhan and Martinez 2012; Eyes et al. 2017). In the absence of cultural burning (fire exclusion), hazelnut and countless other understory species are compromised (Webster and Halpern 2010; Knapp et al. 2013; Wynecoop et al. 2019), along with the Indigenous fire-dependent cultures that rely on these species and processes (Heffner 1984; Ortiz 1993; Mathewson 2007; Smith 2016).

Despite favorable Federal and California state governmental rhetoric toward prescribed fire, centralized government funding and associated programs have been insufficient for sustaining proactive prescribed fire programs in northern California (Quinn-Davidson and Varner 2012; Kolden 2019; Miller et al. 2020). Therefore, governments and institutions can adjust regulations to devolve decision-making to local communities, especially those that have autochthonously established rules, norms, and infrastructure for burning. Given their deep temporal and place-based ties that have motivated the rehabilitation of human-fire relationships integral to their culture, Indigenous communities, such as the Karuk and Yurok, are particularly well positioned to determine the application of prescribed fire in their territories. In regions where cultural burning is less frequent due to legacies of fire exclusion, prescribed fire managers could prioritize the revitalization of these practices in collaboration with American Indian communities to increase support and accelerate expansion (Lake et al. 2017; LeCompte 2018; Lewis et al. 2018; Long and Lake 2018; Wynecoop et al. 2019).

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Appendix A: Contact Information for Key Project Personnel

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Appendix B: List of Completed/Planned Scientific/Technical Publications/Science Delivery Products

Peer-Reviewed Publications

Marks-Block, T. Lake FK, Curran LM. 2019. Effects of understory fire management treatments on California Hazelnut, an ecocultural resource of the Karuk and Yurok Indians in the Pacific Northwest. *Forest Ecology and Management*, 450:117517

Marks-Block, T. Lake FK, Curran LM, Bliege Bird, R. *in review.* Revitalized Karuk and Yurok prescribed burning to enhance California Hazelnut for Indigenous basketweaving, northwestern California, USA. *Fire Ecology*.

Marks-Block, T. *in prep*. Maintaining California black oak (*Quercus kelloggii*) woodlands with cultural fire in Karuk and Yurok territory, Northwest California. To be submitted to *Forest Ecology & Management.*

Marks-Block, T. *in prep*. Facilitating Fire: Redressing Persistent Prescribed Fire Constraints in Northern California. To be submitted to *Fire*.

Report

Marks-Block, T, Lake FK, Bourque, S. 2020. Managing hazel (Súrip) for basketry and nuts. Karuk Tribe Department of Natural Resources, Pikyav Field Institute Management Brief.

Dissertation

Marks-Block, T. 2020. Karuk and Yurok Prescribed Cultural Fire Revitalization in California's Klamath Basin: Socio-Ecological Dynamics and Political Ecology of Indigenous Burning and Resource Management. Doctoral Dissertation, Stanford University, Stanford, California.

Presentations

Lake, FK, and Marks-Block, T. 2020. "Effects of understory fire management treatments on California Hazelnut, an ecocultural resource of the Karuk and Yurok Indians in the Pacific Northwest". Ecological Society of America Annual Meeting, August 3 – 6, 2020. Virtual Conference, Slide Show Presentation.

Marks-Block, T. 2020. "Indigenous Fire Management in California: Revitalizing Culture and Reducing Wildfire Risks Through Prescriptive Burning". Environmental Studies Department Seminar, San Jose State University. February, 19, 2020. San Jose, California. Oral Presentation.

Marks-Block, T. 2020. "Fire Management, Indigenous Burning, and Cultural Revitalization in Northwest California". Anthropology, Geography and Environmental Studies Department Seminar, California State University, East Bay. January, 30, 2020. Hayward, California. Oral Presentation.

Marks-Block, T. 2019. “California Wildfires and the Indigenous Alternative”. World-Ecology Conference, May 30, 2019. San Francisco, CA. Oral Presentation.

Marks-Block, T. 2019. “The Socio-ecological Effects of Burning Hazelnut in Karuk and Yurok Territories.” Northern California Prescribed Fire Council, Annual Meeting, May 7, 2019. Eureka, California. Oral Presentation.

Marks-Block, T. 2019. “Indigenous Burning in Northwest California: Transforming forests and livelihoods.” American Association of Geographers, Annual Meeting, April 7, 2019. Washington DC. Oral Presentation.

Marks-Block, T. 2019. “Karuk and Yurok Cultural Burning Increases Hazelnut Basketry Stem Density.” Yurok Prescribed Fire Training Exchange, March 18, 2019. Pecwan, California. Oral Presentation.

Marks-Block, T. 2019. “Burning for Indigenous Renewal: Karuk and Yurok Indian socioecological restoration in Northwest California”. Dimensions of Political Ecology Conference, February 22, 2019. University of Kentucky, Lexington. Oral Presentation.

Marks-Block, T. 2018. “Indigenous Fire Management in Northwest California: A Model for Ecological and Cultural Restoration”. Stanford University Young Environmental Scholars Conference, November 13, 2018. Stanford, California. Oral Presentation.

Marks-Block, T, and Fredeluces, G. 2018. “Fire Management of American Indian Basket Weaving Plants in the Pacific Northwest.” Northwest Fire Science Consortium. January 25, 2018. Webinar.

Marks-Block, T, and Lake, FK. 2017. “Fire Treatments on California Hazelnut to Enhance Karuk and Yurok Basketry”. 7th International Fire Ecology and Management Congress, November 28 – December 1, 2017. Orlando, Florida. Poster Presentation.

Marks-Block, T, and Lake, FK. 2017. “Yurok and Karuk Indian Prescribed Fire Management in Northwest California: Enhancing the availability of forest resources for community use”. 7th International Fire Ecology and Management Congress, November 28 – December 1, 2017. Orlando, Florida. Oral Presentation.